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ABSTRACT

This report describes laboratory and field procedures appropriate for measuring the effectiveness of active noise reduction (ANR) devices mounted in flight helmets, armoured-vehicle crew helmets, communication headsets, and circumaural hearing protectors. The procedures described are: ear-canal measurements using real subjects or an acoustic test fixture (ATF), masked-threshold and loudness-balance psychophysical procedures, a signal detection procedure, and speech reception procedures using modified rhyme and diagnosic rhyme tests (MRT, DRT) and Speech Transmission Index (STI) measures.

TABLE OF CONTENTS

INTRODUCTION

1.1 The noise levels to which aircraft and combat-vehicle crews are exposed are potentially hazardous to hearing and degrade aural communication. Although noise-excluding ear cups are an integral part of most headgear (flight and vehicle helmets and headsets), their passive attenuation at low frequencies is limited.

1.2 Active noise reduction (ANR) offers a means of increasing the attenuation at low and mid frequencies. Current systems rely on sensing the sound inside a circumaural device and cancelling it by means of negative feedback through a miniature speaker inside the enclosed volume (Wheeler and Halliday (1981)). Noise reduction is limited generally to frequencies below 2000 Hz. Above 1000 Hz, the wavelength of sound approaches the dimensions of the enclosed ear-cup/ear-canal volume, and the performance of the ANR system undergoes wide variations, ranging from minimal noise reduction to noise reinforcement. The intercommunication system (ICS) signal on the earphone line may also be affected by the feedback loop. To counter this and provide some signal enhancement, the ANR electronics may add pre-emphasis to the signal.

1.3 The real-ear-at-threshold (REAT) procedure is the standard method of determining the passive attenuation of a noise-attenuating helmet or headset (ASA STD 1-1975). Because of its principle of operation, the active attenuation* of an ANR system should be evaluated in a moderate to intense noise environment, particularly if the inherent thermal noise of the ANR microphone/amplifier system masks the thresholds of the subjects. Hence, the REAT procedure may not be appropriate.

1.4 This report outlines a number of methods that are thought to be appropriate for the evaluation of headgear mounted ANR systems, either in the laboratory or in the field, as they affect sound attenuation, signal detection, and speech intelligibility.

LABORATORY EVALUATIONS

Active Attenuation

2.1 Three methods of measuring active attenuation in the laboratory are specified in this report. The preferred method is the measurement of ear-canal sound pressures using a miniature microphone on a real head. Two supplementary psychoacoustic methods include noise-masked threshold-shift measurements and loudness-balance estimates.

2.2 The use of a miniature microphone is the most direct means of measuring active attenuation. However, the point of measurement is at the entrance to the ANR-system wearer's ear canal rather than at the eardrum. At frequencies where the ear-canal sound field becomes non-homogeneous, this may yield measures of attenuation that are not repeatable and that differ considerably from those determined psychoacoustically.

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* The active attenuation (positive and negative) of a helmet or headset [fitted with ANR] is the difference in noise levels at the ear of an individual wearing the device with the ANR system switched *ON* and switched *OFF*.

The passive attenuation of a helmet or headset [fitted with ANR] is the attenuation of the device with the ANR system switched *OFF*. It is the difference in an individual's binaural hearing thresholds (threshold shift) when the ears are occluded (wearing the device with the ANR system switched *OFF)* and unoccluded (not wearing the device), or the difference in noise levels inside and outside the device. It should not be assumed that the attenuation of a helmet or headset without ANR remains unchanged when ANR components are installed in the ear cups. Accordingly, when ANR system is added to a helmet or headset, the passive attenuation of the headgear should be measured to determine its protection when the system is inoperative.

The total attenuation of a helmet or headset [fitted with ANR] is the attenuation of the device with the ANR system switched *ON*, and includes the passive and active attenuation components of the device. It is the difference in noise levels at the ear of an individual wearing the device and not wearing the device, or the difference in noise levels inside and outside the device.

2.3 Of the two psychoacoustic tests, the loudness-balance procedure undoubtedly requires less time to complete, is easier for subjects to perform, but may be less accurate. Loudness balances are complicated at some frequencies, however, due to changes in the timbre of the noise between the ANR *OFF* and *ON* conditions when test bands as wide as one-third octave are used. Such changes of timbre do not affect the masked-threshold procedure. However, the masked-threshold task requires the continued attention of the subject, and, because it requires a longer time to complete, is more fatiguing.

2.4 Any pre-emphasis of ICS signals by the ANR system shall be determined to provide correction data for the noise-masking procedure. The pre-emphasis is the difference in ANR-earphone output, produced by pure tones on the ICS earphone line with the ANR system switched *ON* and switched *OFF*, measured in the absence of external noise. The measurements may be made by using a miniature microphone under the helmet or headset worn by a subject, or by placing the headgear on an Acoustic Test Fixture (ATF) (Kunov and Giguere, 1989; Giguere and Kunov, 1989) and measuring the sound pressures under the headgear with the ATF microphone (Forshaw *et al*, 1988; ASA STD 1-1975). The tones shall be centred successively in each of the test-measurement bands used in the evaluation.

Ear-Canal Sound Pressure Measurements

3.1 This method involves the measurement in the one-third octave bands between 125 and 8000 Hz of sound pressures under a helmet or headset, worn by a subject situated in a diffuse noise field. The sound field is acceptable when the sound pressure level (SPL) measured at six positions relative to the centre of a subject's head (without the subject), ± 10 cm in the front/back direction and ± 15 cm in the vertical and left/right directions, shall remain within 6 dB for all test bands. The difference in SPLs between the left/right positions shall not exceed 2 dB. The sound shall be generated in a room whose reverberation time in the test space (without subject) shall be less than 1.6 seconds for each test band. Additional test-band measurements should be made below this range (20 to 100 Hz), although it is realized that the sound field characteristics in these one-third octave bands may not meet the above sound-field requirements.

3.2 The sound source shall provide an electrical noise signal with uniform spectral density from 20 to 16000 Hz. The output of the noise source should be passed through a "pink-noise filter" (equal energy per octave band) to facilitate the one-third octave-band requirements specified in paragraph 3.1. The one-third octave-band SPL measured at the subject's head location for each test-band frequency shall not be less than 85 dB and shall be at least 60 dB higher than the SPL of the test-room noise floor in the test band. The gain and inherent noise characteristics of the measurement system shall be such that its signal-to-noise ratio is never less than +10 dB.

3.3 The miniature microphone used to measure the sound pressure at the subject's ear shall be of minimum size and no greater than 8.00mm x 7.25mm x 5.0mm (LxWxH). When the microphone is loaded with the measurement system impedance, its normal-incidence free-field response shall not deviate more than 3 dB, referenced to 1000 Hz, between the lowest- and highest-frequency test bands to be investigated. The miniature microphone shall be positioned at the entrance to the ear canal in the centre of the concha volume (midconcha). To ensure that it is positioned at the same anatomical location for each subject and measurement occasion, it may be advisable to employ a microphone holder similar to the type shown in Figures 1 and 2. Any such device should not disturb the seal of the ear-cup cushion, occlude the wearer's ear canal or otherwise change the sound field in the enclosed volume so that the operation of the ANR is affected.

3.4 The miniature microphone shall be connected to an external amplifier by a ribbon or equally thin cable in order that the seal between the ear cup cushion of the headgear and the circumaural surface of the head is minimally disturbed. The microphone and cable shall be secured to the external ear and neck so that the microphone position remains relatively fixed as the ear cups are donned and doffed. Except for the circumaural shell of the headgear, the subject's ear canal and volume shall not be occluded during the measurements.

3.5 The fitting of a flight or vehicle helmet is critical to the performance of its ANR system. Therefore, it shall be fitted in accordance with CF fitting procedure (Anon, 1986,1984) to achieve *an experimenter-supervised fit*. Eyeglasses shall not be worn by the subject. After the headgear has been donned, a wide band white noise shall be introduced into the test area at a level of at least 70 dB SPL at the subject's position. The subject shall be instructed to manipulate the headgear until satisfied that the noise is minimal with the ANR system *OFF*, and that there is no audible instability when the ANR system is switched *ON*. After the test is begun, further manipulation of the headgear shall not be permitted.

3.6 Some means shall be employed to provide a reference for maintaining the subject's head in a constant position (not a head rest). The device (e.g., a plumb bob) shall not transmit to the subject's head any vibrations that might affect the measurements or present a reflective or absorptive surface that might alter the level of the sounds at the ears of the subject.

3.7 Measurements shall be made simultaneously at four microphone locations (under the right and left ear cups of the headgear, and outside the headgear .20± .02 metres to the side of each ear cup, directly opposite each ear canal on a plane with the wearer's eyes) in each one-third octave band between 20 and 8000 Hz, as a function of ANR switched *ON* and switched *OFF*. The external microphones shall be the same type and model as those used inside the helmet or headset.

3.8 The measurements shall be repeated three times for each subject and the headgear shall be doffed and donned on each occasion. In addition to the active attenuation, the passive and total attenuations of the headgear/ANR system (see paragraphs 7.1 and 7.2) shall be computed for each one-third octave test-band. The difference between the inside levels in a given one-third octave band with the ANR system *ON* and *OFF* may be taken as a measure of the active attenuation in that band. The difference between the inside and outside levels in a given one-third octave band with the ANR system *ON* may be taken as a measure of the total attenuation in that band. The difference between the inside and outside levels with the ANR system *OFF* may be taken as a measure of the passive attenuation in that band. The mean values of these attenuations shall be determined by averaging all the respective attenuation values for all subjects. The standard deviations of the mean values shall be computed using the number of observations minus one (n-1).

3.9 If feasible, the external noise level at which the ANR system begins to overload shall be determined. The measurements shall be made in the test field described in paragraph 3.1 in the one-third octave bands of interest. The measurements may be made by using the miniature microphones under the headgear worn by a subject (paragraph 3.7), or by placing the headgear on an acoustic test fixture ATF having an acoustic isolation of no less than 60 dB in any test frequency band in the range of interest (Forshaw *et al*, 1988), and measuring the sound pressures under the headgear with the ATF microphone. The onset of ANR system overload in a given test frequency band shall be defined as the level of the noise field at which incremental increases in its SPL no longer produce equal increases in the test band SPL under the headgear (i.e., there is a decrease in active attenuation). If the noise generating system used for this test is not capable of producing SPLs sufficiently intense to reach the onset of overload of the ANR system in any test frequency band, this shall be reported along with the maximum level for the test frequency band at which incremental increases in the noise field SPL continued to produce equal increases in the test band SPL under the headgear.

Psychoacoustic Methods

4.1 Each subject shall be screened for normal hearing (i.e., hearing threshold levels not greater than 10 dB at the test frequencies between 125 and 1000 Hz and not greater than 20 dB at the test frequencies between 2000 and 8000 Hz). The subject shall be situated in the test field described in paragraph 3.1, wearing the headgear with the ANR system under test. In the loudness-balance procedure, it may be desireable to use test bandwidths less than one-third octave to minimize any problem of timbre changes. The position of the subject's head shall be maintained as described in paragraph 3.6, and if the headgear is a flight or vehicle helmet, it shall be fitted as described in paragraph 3.5.

4.2 It is essential that the test procedure to be used be clearly understood by the subject. This shall be accomplished by a verbal briefing and demonstration of the task, after which the subject shall be asked if he has understood. If there is any doubt, the briefing and demonstration shall be repeated. Each subject shall be given one or more practice sessions until the investigator is satisfied that the subject has learned the procedure. At least two definitive tests shall be made with each subject. The number of tests shall be the same for all subjects.

Noise-Masked Threshold-Shift Procedure

5.1 In this procedure, the earphones in the helmet or headset shall be used to present test tones to the subject so that his masked thresholds can be determined in the test bands specified in paragraph 3.1 when the ANR system is switched *ON* and switched *OFF*. The change in masked threshold between the two conditions, corrected to account for any pre-emphasis of ICS signals (i.e., the test tones) when the ANR is *ON* (see paragraph 1.2), is the measure of the active attenuation of the ANR system.

5.2 Any psychophysical procedure suitable for threshold determinations of individual test tones shall be used. A recommended procedure is to present the signal at a level that is audible above the one-third octave-band masking noise, to decrease the level until the signal is not heard, and then to increase the level until the tone is just heard. The masked threshold is considered to be the lowest level of the signal which is heard on at least 50 per cent of the trials during three or four ascents and descents across the lowest-level value.

Loudness-Balance Procedure

6.1 In this procedure, the sound field shall be changed once per second between two levels. Simultaneously, the ANR system shall be switched *ON* during the more intense, and *OFF* during the less intense of the two diffuse-field periods (see Figure 3). The subject shall be instructed to balance the levels for equal loudness by adjusting the level difference between the two diffuse-field sounds, the adjustment being made during the ANR *OFF-interval*. The resulting difference in sound level outside the ear cup shall be taken as the active attenuation of the ANR system.

Passive and Total Attenuation

7.1 The standard method of measuring the passive attenuation of a helmet or headset is the REAT procedure (ASA STD 1-1975). It should be noted, however, that attenuation data derived by the REAT procedure may be affected by an enhancement of the physiological-noise in the auditory canals when they are occluded (the occlusion effect). The result is a low-frequency masked threshold determination when the headgear is worn, and an accompanying overestimation of attenuation. In addition, at frequencies above 1500 Hz, direct measures by microphone of headgear attenuation may yield higher values of attenuation than can be obtained by the REAT procedure. Sound is able to reach the inner ear by way of the bones and tissue of the head (body- or bone-conducted sound) as well as through the outer and middle ears (air-conducted sound). The active and total attenuations of a helmet or headset should not be determined by the REAT procedure (see paragraph 1.3) and the preferred method is by direct microphone measure. Accordingly, the method specified in this report for determining the passive attenuation of a helmet or headset fitted with ANR is by direct microphone measure in order that passive, active and total attenuation data will be subject to the same procedural anomalies.

7.2 The passive and total attenuations of the helmet or headset shall be determined by measuring the one-third octave band sound pressure levels outside and inside the headgear in accordance with paragraphs 3.3, 3.4, 3.7 and 3.8. The difference between the inside and outside levels in a given one-third octave band with the ANR system *ON* may be taken as a measure of the total attenuation in that band. The difference between the two levels with the ANR system *OFF* may be taken as a measure of the passive attenuation in that band.

Signal Detection

8.1 In certain air operations (e.g., ASW active sonar), the effect of ANR upon the ability of listeners to detect/discriminate auditory signals may require investigation. This may be accomplished using the general procedure described in paragraph 5.2. The frequency of the test tones shall be representative of those used during specific operations, and the masking noise shall be a broadband reproduction of the ambient noise encountered in the aircraft during those operations.

8.2 The difference in the masked-threshold at each test frequency for the ANR *OFF* and *ON* conditions shall be taken as a measure of the effect of ANR on signal detection performance. The subject, screened for normal hearing (see paragraph 4.1), shall be situated in the simulated noise field described in paragraph 8.1 wearing the headgear fitted with the ANR system under test. The position of the subject's head shall be maintained as described in paragraph 3.6, and if the headgear is a flight or vehicle helmet, it shall be fitted as described in paragraph 3.5.

8.3 Any improvement in signal-detection performance may not be directly related to noise reduction *per se*, since a reduction in the low-frequency energy of the masking noise by ANR may affect the masked threshold of higher-frequency signals due to upward spread of masking (Wegel and Lane, 1924). Hence, the measure is specific to the detection task and the masking spectrum in which it is performed.

Speech Reception

9.1 In this report, two procedures are outlined for the evaluation of ANR on speech reception: a subjective measure of speech intelligibility and an objective measure of speech transmission (STIDAS II). In the evaluation, a subject shall be situated in a noise field that is a reproduction of the noise(s) encountered during specific air operations. The subject shall wear the headgear fitted with the ANR system under test. The position of the subject's head shall be maintained as described in paragraph 3.6 and if the headgear is a flight or vehicle helmet, it shall be fitted as described in paragraph 3.5.

9.2 Overall intelligibility is governed by system parameters (e.g., bandwidth, spectrum enhancement, dynamic range) and the acoustic environment of the listener. Hence the resulting measure of the effect of ANR on communications is specific to the system and environment in which the evaluation was conducted.

Speech Intelligibility Procedure

10.1 The preferred method of evaluating the effect of ANR on speech reception involves the measurement of intelligibility. Three tests commonly used for this purpose are the phonetically balance (PB) word test, the Modified Rhyme Test (MRT) (House *et al*, 1965) and the Diagnostic Rhyme Test (DRT)(Voiers, 1967). The PB word test consists of 1000 monosyllable words compiled into 20 lists of 50 words. It has the advantage of a large vocabulary size and is useful when evaluating or comparing systems because of its sensitivity to small change. Its disadvantage is that the test is difficult to administer and to score. It is time consuming because subjects must write the stimulus word and be trained extensively.

10.2 The MRT consists of a number of 50-word lists of American English monosyllable words, each having the form Consonant-Vowel-Consonant (CVC). Subjects' answer sheets or video display screen show each stimulus word in a closed set of six rhyming words, differing only in the initial or final consonant. Within each test list of 50-word ensembles, there are an equal number with differing initial consonants and with differing final consonants. The relation between the scores obtained with PB word lists and the MRT has been published by Kryter and Whitman (1965). The DRT consists of paired CVC rhyming words that differ only in their initial consonants.

10.3 A recommended rate of presenting the MRT stimulus words aurally is one item every four seconds in the carrier phrase "The next word is _______". The recommended rate for the DRT words is one every 1.5 seconds without a carrier phrase. Results from these tests have been shown to be highly correlated with results obtained using vocabularies representative of operational communications (Webster, 1972). Unless specific requirements dictate otherwise, the MRT shall be the intelligibility test to be used in the laboratory for evaluating ANR systems (ASCC 61/49, 1986a).

10.4 Percentage intelligibility scores shall be corrected for chance using the relation:

$$PC=2(WC-\frac{50-WC}{A-1})$$

where PC is the corrected per cent intelligibility for the 50-word list, WC is the number of words marked correctly, and A is the number of response-set alternatives (Allen and Yen, 1979).

10.5 Among the variables that shall be controlled or monitored during the course of intelligibility testing are (1) the talker's and listener's familiarity with the speech material used, (2) the talker's level and pacing of speech, (3) the spatial and temporal characteristics (e.g., reverberation) and background noise level (ambient or aircraft/vehicle-simulated) of the talker's and listener's environments, (4) the microphone's location relative to the talker's mouth if the microphone is not mounted within a mask, and (5) the talker's feedback or sidetone level. For each test condition, the listener shall adjust his volume control so that the speech signal is set to the most *effective speech-reception* level. It shall be explained to subjects that the most *effective speech-reception* level is not necessarily the maximum setting of the volume control, and that at such a setting, the overload distortion of the speech signals may reduce intelligibility and speech-reception effectiveness. If it is feasible, a means of monitoring subjects' volume control settings shall be instituted to ensure that such settings are reasonable.

10.6 Percentage correct intelligibility shall be determined in the aircraft/vehicle noise at typical ICS-signal (long-term rms) levels with the ANR switched *ON* and switched *OFF*. At least five talkers, and at least two word lists per talker, shall be used for each test condition. The difference in the intelligibility for the two conditions shall be taken as a measure of the effect of the ANR on speech reception.

STIDAS II Procedure

11.1 A much quicker, less expensive, but less accurate method of estimating speech reception in noise and bandpass-limited conditions involves the use of artificial speech signals generated by the STIDAS II speech-transmission measuring system (Steeneken and Houtgast, 1980). The Transfer Index (TI) from each of the octave bands between 125 and 8000 Hz, weighted in proportion to the contribution of the band to the intelligibility of speech, is summed to give an overall index, defined as the Speech Transmission Index (STI) of the channel.

11.2 The relationships between STI and the intelligibility of PB words and MRT scores are given in Figure 4. STI values may range from 0.0 to 1.0, indicating complete unintelligibility and complete intelligibility respectively. There is a relatively large prediction error associated with the STI estimates of intelligibility (σ=5.6 per cent (Steeneken and Houtgast, 1981; Anderson and Kalb, 1987)). Hence, small (although significant) changes in the mean values of STI due to changes in the performance characteristics of an element of a communication system, cannot be assumed to represent significant changes in speech intelligibility. The STIDAS II signal is a random noise with a spectrum shape corresponding to that of average speech spectrum between 125 to 8000 Hz. The modulation functions of each of the seven octave bands in this frequency range are sinusoidal; the signals of the other six octave bands are modulated with separate uncorrelated random envelopes corresponding to the envelope function of running speech. The randomness of the signals is a source of replication variance (Steeneken and Houtgast, 1981).

11.3 The STIDAS II signals shall be delivered to the ANR system through the earphones in the headgear, either worn by a subject or fitted on an ATF, and the resulting aircraft/vehicle noise and artificial speech signals at the ear canal shall be returned to the STIDAS II analyzer section using a miniature microphone (see paragraph 3.3) or the ATF microphone when the ANR system is switched *ON* and switched *OFF*. The STIDAS II signal shall be calibrated to have appropriate equivalent speech levels (e.g., 80, 90, 100 dBA with the ANR system *OFF)* measured by the miniature microphone.

11.4 In this procedure the effect on ANR performance of the simulated aircraft/vehicle noise, introduced into the ICS through a talker's microphone, will not be included in the evaluation unless noise from an open microphone can be mixed acoustically with the STIDAS II signals. This may be accomplished with an acoustic head simulator having a built-in artificial voice and mouth to produce the near-field sound spectra and levels generated by an average adult speaker in the ambient or simulated aircraft/vehicle noise (Kunov and Racansky, 1988). With such a device, the STIDAS II signals shall be delivered to the microphone (of the headgear mounted on the head simulator) through the artificial voice at realistic speech levels, and the resulting electrical signals shall be delivered through the ICS to the ANR system and STIDAS II analyzer section as described in paragraph 11.3.

11.5 At each SPL, the intelligibility (octave-band Transfer Indexes (TI) and overall Speech Transmission Indexes (STI)) shall be determined, based on five samples of the speech signal, in the aircraft/vehicle noise as a function of ANR switched *ON* and switched *OFF*. Values of STI shall be converted to corresponding values of speech intelligibility using Figure 4 or other published data. Bearing in mind the relatively large prediction error associated with STI estimates of intelligibility (paragraph 11.2), the difference in intelligibility for the two conditions may be taken as a measure of the effect of the ANR on speech reception at the given ICS-signal level.

Reporting of Laboratory Evaluations

12.1 In reporting the results of the evaluation, the investigator shall include the following information:

(i) As required, the active, passive and total attènuation in dB in each one-third octave test-band, the mean change in detection performance in dB at each test frequency, and/or the mean change in intelligibility at each ICS signal level evaluated.

(ii) The standard deviation in dB in each one-third octave test-band, computed using the number of observations minus one (n-1).

(iii) The test procedure and method employed in the investigation.

(iv) The spectrum (in octave or one-third octave SPLs) of any masking noise.

(v) The number of subjects, talkers (for intelligibility testing), and replications.

(vi) Type of helmet fitting followed during the evaluation.,

(vii) The external noise level at which the ANR system begins to overload and the procedure employed to determine this level (see paragraph 3.8).

(viii) Type and model number of any microphone used in the investigation.

(ix) Type of ANR system, helmet and/or headset, ICS, and the different size(s) of helmet used in the investigation.

FIELD EVALUATIONS

13.1 Before an ANR system is introduced into service, the system shall undergo evaluation in the field to ensure that its stability and acoustic performance are not degraded by elements in the operating environment such as high levels of noise and vibration, heat, cold, humidity, etc. The evaluation should include the measurement of the passive, active and total attenuation of the helmet or headset, and as much as possible, should be the same as or similar to the laboratory measurements that preceded the field evaluations.

13.2 The evaluation should also include a questionnaire to obtain a subjective assessment of the ANR system. The questionnaire should solicit comments regarding the stability of the ANR system under the various conditions in which it was used (e.g., high-altitude, high-G, intense-noise and vibration environments), its effect on communications and other auditory tasks, its reliability and maintainability, its effect on helmet comfort and donning/doffing procedures, etc.

Active, Passive and Total Attenuation

14.1 The method specified in this report for evaluating active, passive and total attenuations in the field involves the measurement of one-third octave-band sound pressures outside and under the headgear (see paragraphs 3.3, 3.4, 3.7 and 3.8) worn by individuals at appropriate crew stations during the aircraft or vehicle operating conditions most likely to degrade the operation of the ANR system (e.g. the most intense noise and vibration conditions).

14.2 Because of the restricted space at some crew stations, and the fact that the head may move voluntarily or involuntarily while the aircraft or vehicle is in motion, the positioning of the external microphones 0.20 metres to each side of the helmet or headset (see paragraph 3.7) may not be practical or convenient. Accordingly, the external microphones may be taped to the outside of the ear cups. However, the response of the microphone at this location shall be determined in each one-third octave band of interest, relative to its response when located 0.20 metres to the side of the ear cup. The relative response shall be used to correct sound-pressure readings taken when the external microphone is attached to the headgear, to equivalent readings taken at a distance of 0.02 metres.

14.3 If the headgear is a flight or vehicle helmet, it shall be fitted in accordance with paragraph 3.5. The miniature microphones, and their attachment to the subject, shall be in accordance with paragraph 3.3. If the time available in the aircraft or vehicle precludes the replication of test conditions, the measurements need only be carried out once with each subject tested.

14.4 The miniature microphones shall be interfaced to an analogue or digital recording system. Noise samples for the ANR system switched *ON* and switched *OFF* conditions shall be at least one minute in duration. If the noise levels vary considerably during the sampling time, the sample durations should be extended accordingly. The complete equipment shall be capable of measuring the pressure levels encountered in the operating environment with respect to dynamic and frequency range, and accuracy. Measurement results shall include a description of the system, the method of calibration, and the character of the noise (e.g., discrete tonality, intermittency).

14.5 Prior to use, the complete equipment shall be calibrated and checked in the laboratory to ensure accuracy of reading and proper operation under the expected measurement conditions. The equipment shall be calibrated in the field immediately before and after use.

14.6 The mean active, passive and total attenuations shall be computed at each crew or operator position in each one-third octave test-band by averaging the relevant attenuation values measured for all subjects at that position. The standard deviation of the mean value of active attenuation shall be computed using the number of observations minus one (n-1).

14.7 Preferably, the helmet or headset shall be disconnected from the ICS during the test. Otherwise, there shall be no voice messages or signals on the ICS, all microphones on the circuit shall be *OFF*, and the volume control shall remain fixed. If the time available in the aircraft or vehicle precludes the replication of test conditions, the measurements need only be carried out once with each subject tested.

Signal Detection

15.1 Because of the difficulty of controlling experimental conditions in the field (e.g., noise-level constancy and repeatability, turbulence-induced vibration), this report does not specify a rigorous psychoacoustic procedure for evaluating the effect of ANR on signal detection. Nevertheless, it may be desirable to test an ANR system in the field since signal detection is affected by the masking effects of the noise in which it is performed (noise which may not be adequately reproduced in the laboratory), and by the performance of the ANR system in the operating environment. Accordingly, the following method is suggested as a means of conducting such testing.

15.2 Each subject shall be screened for normal hearing (see paragraph 4.1). If the headgear to be worn is a flight or vehicle helmet, it shall be fitted in accordance with paragraph 3.5. The subject shall be located at one or more of the crew stations where signal-detection tasks are carried out. Testing shall be conducted in the aircraft or vehicle during the operating profiles encountered during signal-detection operations.

15.3 Using signals from the aircraft/vehicle system, or, tones introduced electrically through the ICS line-input, the subject shall reduce the level of the audio presentations with the volume control until each presentation is just audible, with the ANR switched *ON* and switched *OFF*. The electrical level of the signal on the helmet or headset earphone line shall be measured for each setting. The mean difference in the voltage levels (in dB), based on four or more pairs of measures for the ANR switched *ON* and switched *OFF* conditions, shall be taken as a measure of the effect of ANR on signal detection performance. The frequency of the test tones shall be representative of those used during specific air operations. Any manual AGC in the system shall not be changed during testing.

Speech Reception

16.1 Because the effect of an ANR system on speech reception may be governed by the performance of the system in the operating environment and by the parameters of the aircraft/vehicle ICS (e.g., bandwidth, spectrum enhancement, dynamic range, system noise), it may be desirable to test an ANR system in the field. Two procedures are outlined for the evaluation of ANR on speech reception in the field: a speech intelligibility procedure and a speech transmission index device using artificial signals (STIDAS II) procedure.

Speech Intelligibility Procedure

17.1 Each subject shall be screened for normal hearing (see paragraph 4.1). If the headgear to be worn is a flight or vehicle helmet, it shall be fitted in accordance with paragraph 3.5. The subject shall be tested at one or more of the crew stations where communications are carried out during typical operating profiles.

17.2 Speecn-intelligibility test stimuli may be prerecorded under controlled conditions (see paragraph 10.3) and introduced into the aircraft/vehicle ICS. In this case the effect on ANR performance of aircraft/vehicle noise, introduced into the ICS through the talker's microphone, will not be included i. the evaluation unless noise from an open microphone can be mixed electrically with the recorded speech. Alternatively, the test stimuli may be tape recorded off the ICS system-line during a pre-test flight for subsequent intelligibility testing during the test flight or ride, or read directly to subjects at the time of the test run.

17.3 At least two word lists should be used for each test condition (i.e., ANR switched *ON* and switched *OFF).* Since flying conditions (e.g., vibration) may make it difficult for subjects to scan the six rhyming-word set (and mark the appropriate response) of the MRT as opposed to the two word set of the DRT, use of the DRT lists may be more appropriate (see paragraph 10.2).

17.4 Percentage intelligibility scores shall be corrected for chance in accordance with paragraph 10.4. Among the variables that shall be controlled or monitored during the course of the intelligibility testing are (1) the talker's and listener's familiarity with the speech material used, (2) the talker's level and pacing of speech (3) if the microphone is not mounted within a mask, its location relative to the talker's mouth, (4) his feedback or sidetone level, and the noise levels at the talker's and listener's positions. For each test condition, the listener shall adjust his volume control so that the speech signal is set to the *most comfortable level.*

STIDAS II Procedure

18.1 An alternative procedure for evaluating the effect of ANR on speech reception in the field involves the use of prerecorded (tape-source) artificial speech signals generated by STIDAS II (paragraph 11.1). The signals include a synchronization signal which is used by the analyzer section of the STIDAS II system when signal generation and analysis do not occur at the same time (Steeneken and Houtgast, 1981).

18.2 The tape-source STIDAS II signals shall be introduced electrically through the ICS line-input to the helmet or headset earphones. The resulting aircraft/vehicle noise penetrating the headgear and the STIDAS II signals at the subject's ear shall be measured and tape recorded (tape-result signals) when the ANR system is switched *ON* and switched *OFF*, using a miniature microphone (see paragraph 3.3). In this procedure the effect on ANR performance of aircraft/vehicle noise, introduced into the ICS through a talker's microphone, will not be included in the evaluation unless noise from an open microphone can be mixed acoustically with the STIDAS II signals. The level of the tape-source signals shall be adjusted so that the listener's gain-control setting and signal level on the helmet or headset earphone line is the same as that normally produced by "live" running speech.

18.3 The tape-result signals shall be analyzed by the STIDAS II system to determine the intelligibility (octave-band TIs and overall STI), based on five samples of speech signal prerecorded on the source tape, as a function of ANR switched *ON* and switched *OFF*. Values of STI shall be converted to corresponding values of speech intelligibility using Figure 4 or other published data. Bearing in mind the relatively large prediction error associated with STI estimates of intelligibility (see paragraph 11.2), the difference in intelligibility for the two conditions may be taken as a measure of the effect of the ANR on speech reception at the given intercom-signal level.

Reporting of Field Evaluations

19.1 In reporting the results of the evaluation, the investigator shall include the following information:

(i) As required, the active, passive and total attenuation in dB in each one-third octave test-band, the mean change in detection performance in dB at each test frequency, and/or the mean change in intelligibility.

(ii) The standard deviation in dB in each one-third octave test-band, computed using the number of observations minus one (n-1).

(iii) The aircraft/vehicle operating conditions under which the evaluations were conducted.

(iv) The location of the measurements and the number of subjects and replications.

(v) The test procedure and method employed in the investigation.

(vi) The spectrum (in octave or one-third octave SPLs) of any masking noise.

(vii) Type of helmet fitting fitting followed during the evaluation.

(viii) Type and model number of any microphone used in the investigation.

(ix) Type of ANR system, aircraft or vehicle, ICS and other systems, helmet and/or headset, and the different sizes of helmet used in the investigation.

(x) The results of subjective assessments obtained by questionnaire.

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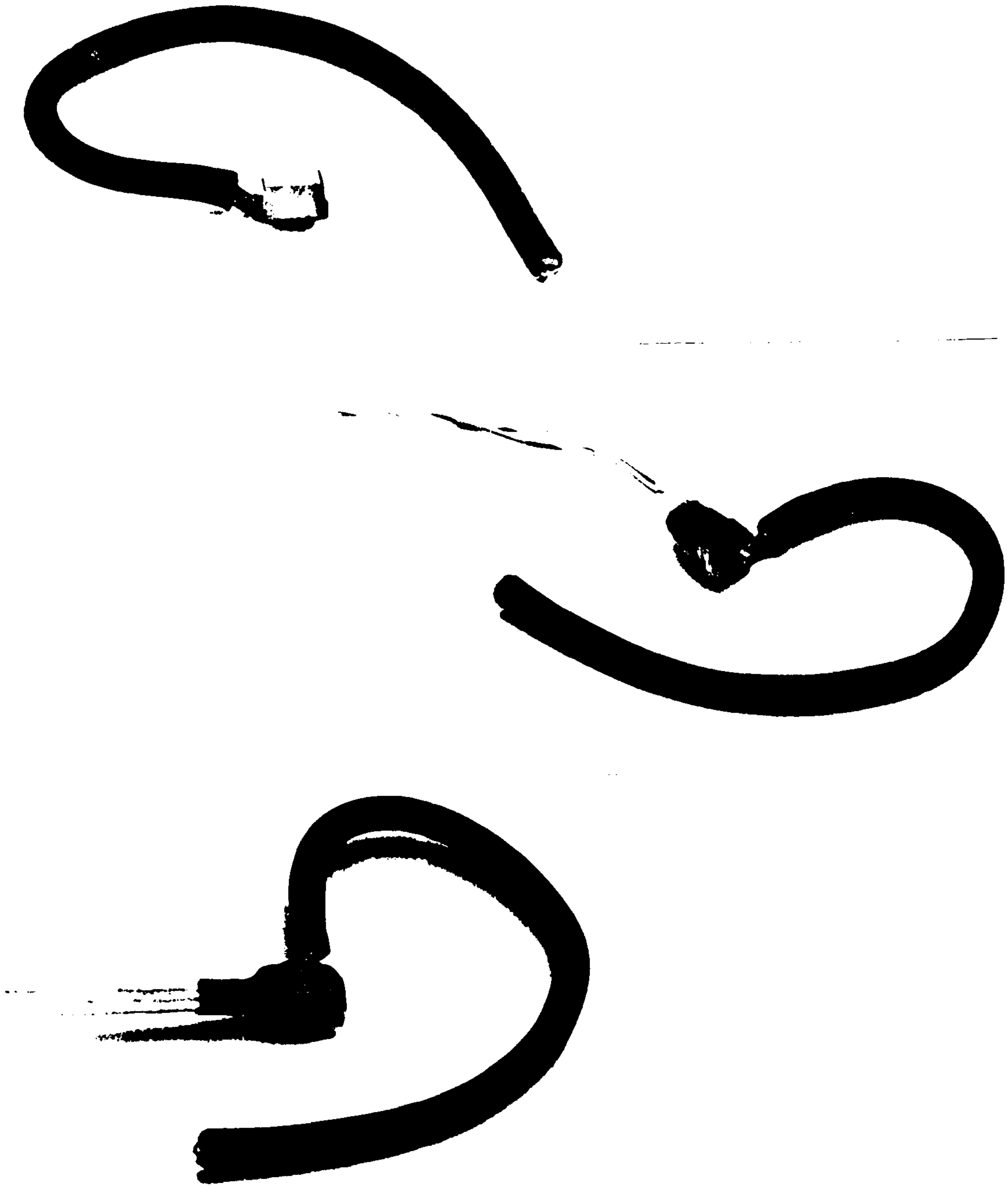

FIGURE 1. Holder for positioning a miniature microphone under a circumaural earmuff *(upper left)*; the Knowles microphones BL 1785 *(middle right)* and BT 1759 *(lower right)* in the holder.

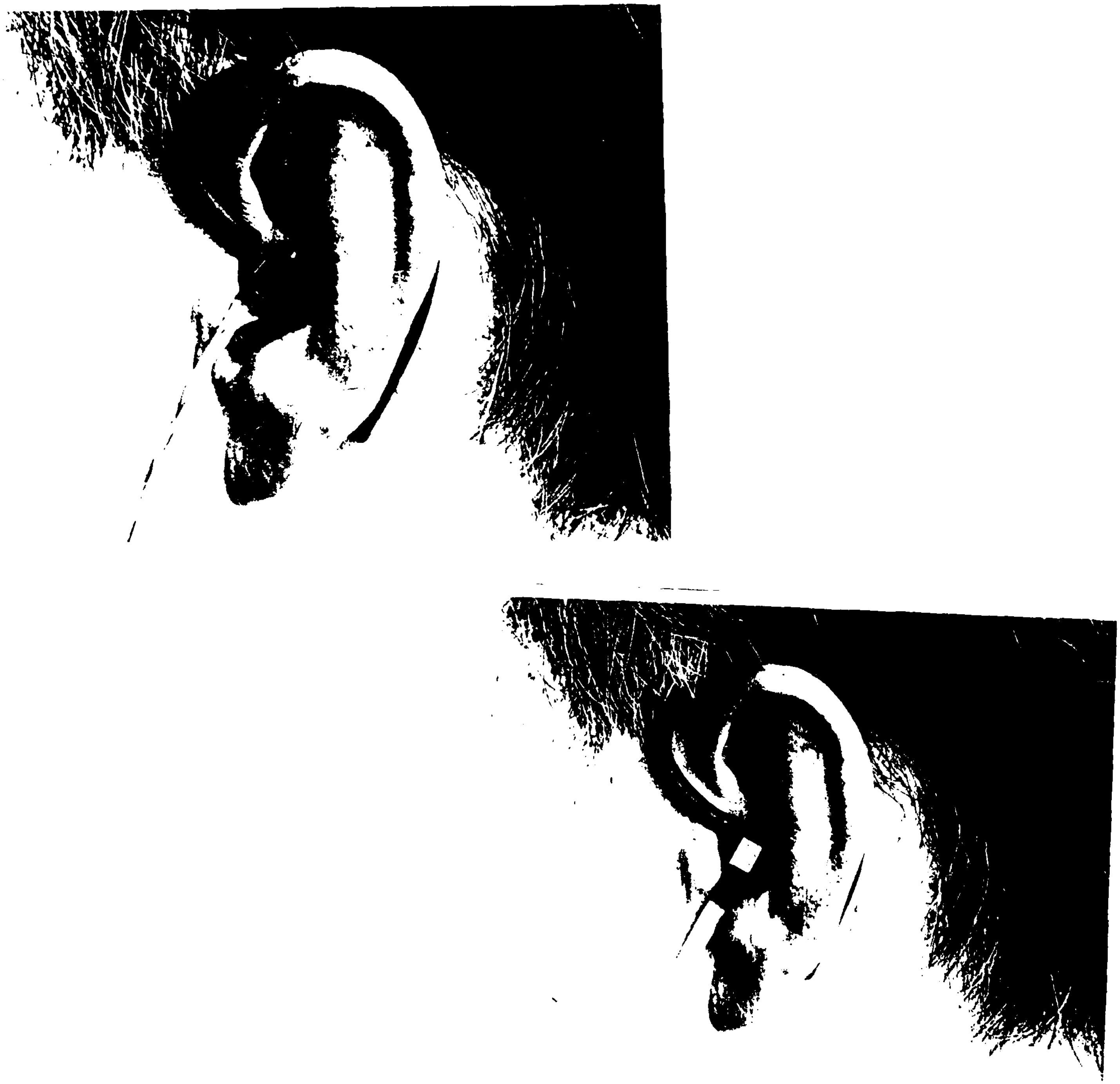

FIGURE 2. Holder with a Knowles BL 1785 microphone *(upper left)* and BT 1759 microphone *(lower right)* positioned at the entrance to a subject's ear canal in the centre of the concha volume (midconcha).

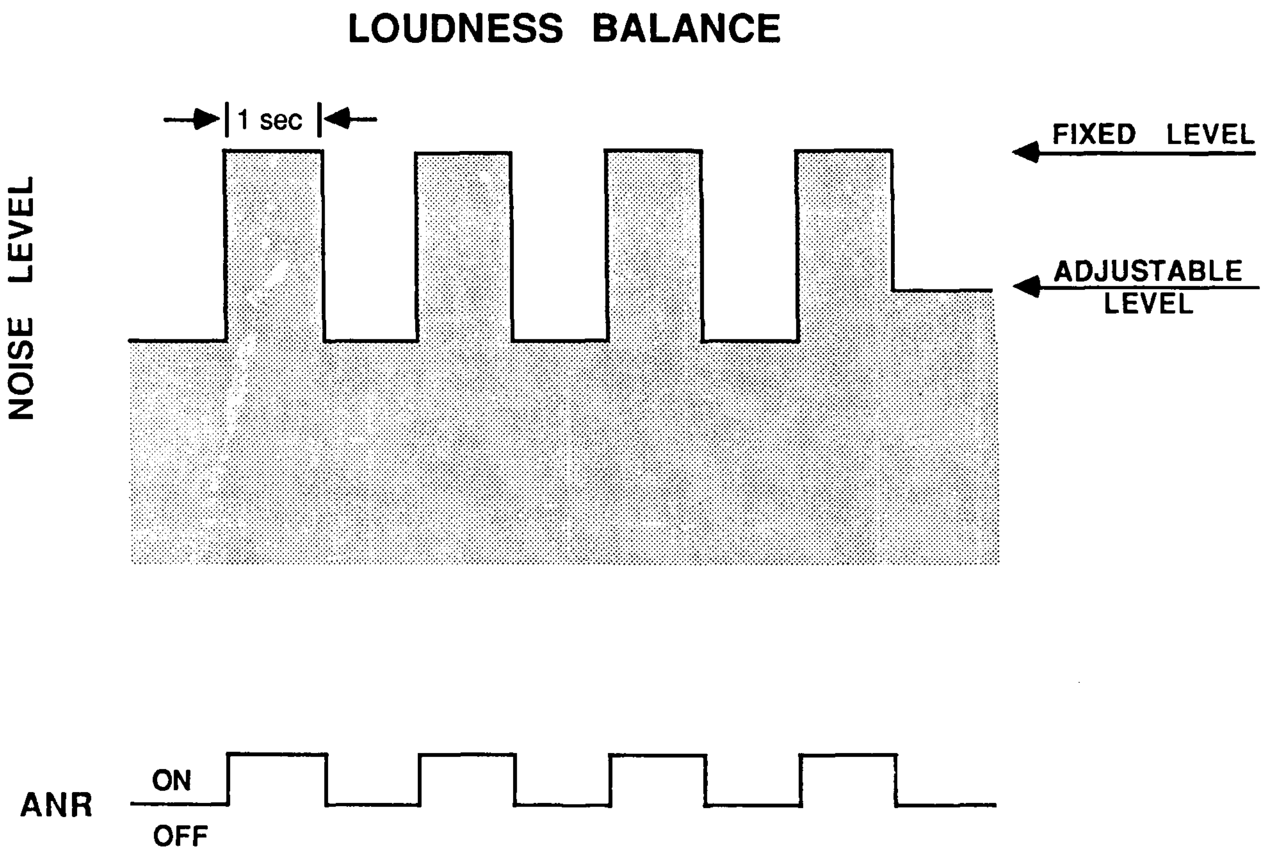

FIGURE 3. Time relationship between ANR *ON/OFF* conditions and changes in diffuse-field noise levels. Loudness balance between the two ANR conditions is achieved by adjusting the level of the noise during the *OFF* condition.

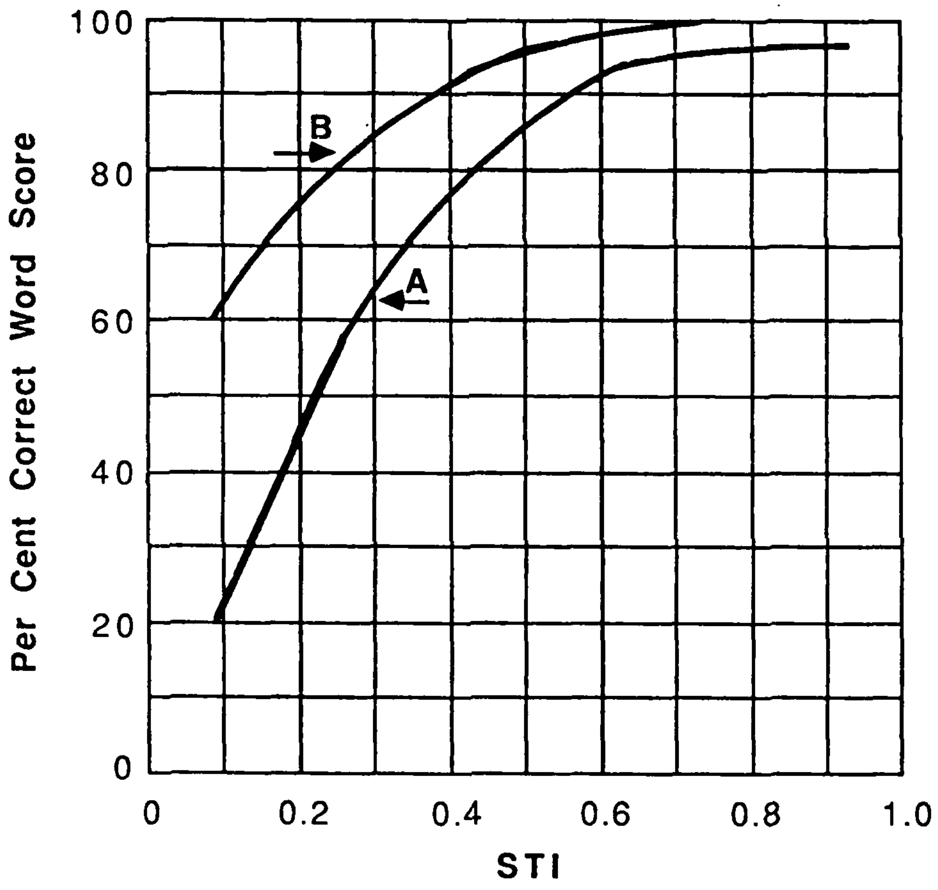

FIGURE 4. Relationship between Speech Transmission Index (STI) and percentage correct PB English words *(A)* (Anderson and Kalb, 1987). Shown also is the relation between STI and MRT *(B)* (derived by Anderson and Kalb after Kryter and Whitman, 1965).

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ABSTRACT

This report describes laboratory and field procedures appropriate for measuring the effectiveness of active noise reduction (ANR) devices mounted in flight helmets, armoured-vehicle crew helmets, communication headsets, and circumaural hearing protectors. The procedures described are: ear-canal measurements using real subjects or an acoustic test fixture (ATF), masked-threshold and loudness-balance psychophysical procedures, a signal detection procedure, and speech reception procedures using modified rhyme and diagnosic rhyme tests (MRT, DRT) and Speech Transmission Index (STI) measures.

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